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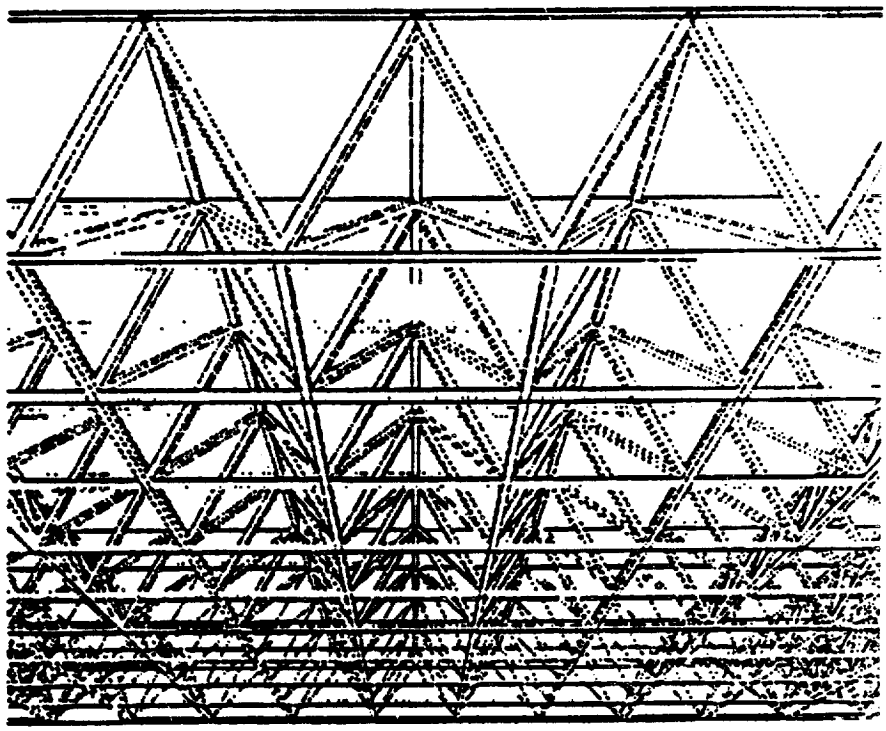
PATHFINDER

NASA Ames Research Center
Human Performance Research Laboratory
Moffett Field, California



Final Technical Report

to Meet Requirements of
NASA Ames Agreement NAG 2-635
November 1994

Colin Clipson, Principal Investigator

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Architecture Planning Research Laboratory/University of Michigan

Introduction

This paper will review and summarize research initiatives conducted between 1987 and 1992 at NASA Ames Research Center by a research team from the University of Michigan Architecture Research Laboratory.

These research initiatives, funded by a NASA grant NAG 2-635, examined the viability of establishing collaborative, reconfigurable research environments for the Human Performance Research Laboratory at NASA Ames in California.

Collaborative Research Environments are envisioned as a way of enhancing the work of NASA research teams, optimizing the use of shared resources, and providing superior environments for housing research activities. The Integrated Simulation Project at NASA, Ames Human Performance Research Laboratory is one of the current realizations of this initiative.

This paper is presented by Project Director Colin Clipson of the University of Michigan, with Leon Harrison the NASA Project Monitor and Katarina Tomovic, Research Associate at the University of Michigan.

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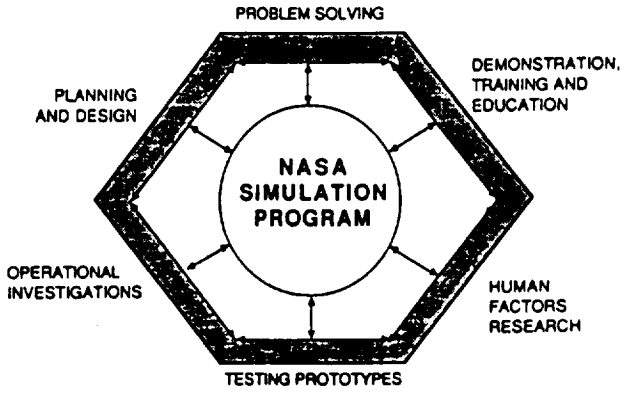
1.0 HPRL Integrated Simulation Project

The HPRL Integrated Simulation Project began as an investigation of projected uses for the High Bay space at the Human Performance Research Laboratory (HPRL) at the NASA Ames Research Center in Moffett Field, California. At that time, HPRL's High Bay facility was in the drawing stage only — an empty space without specific provision for use. To ensure the continuing compatibility of High Bay uses with HPRL research programs, the High Bay was conceived as a **reconfigurable** performance environment. In such a space, physical and environmental characteristics could be tailored to meet the needs of a spectrum of specific experiments. **Ref. 1**



NASA simulation program.

A primary aim of this study was to further the overall efficiency and performance of the HPRL by encouraging the use of generic mock-ups or environments. This type of use would reduce the cost and time required for fabrication, assembly and development, as well as maximizing the benefits of cost sharing and space use. Goals of the grant were constrained by cost and suitability factors. For instance NASA required that all hardware and software considered for potential use be readily available on the open market. (Research programs do not generally carry sufficient funds to allow extensive R&D efforts just to develop research apparatus.) Some adaptation and "tailoring" of off the shelf software was allowable, but only when it

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1. Clipson, C., HPRL Integrated Simulation Project, HPRL, NASA Ames Research center, APRL, The University of Michigan, January 1988.

greatly enhanced the utility of the basic environment. The second major constraint was that any hypothetical research environments to emerge from the study must be configured to support ongoing or planned research activities. To promote efficient use of available resources and personnel, a planning and management system was proposed that would integrate research activities in the High Bay space with adjacent areas both within and outside of the building. **Ref. 1**

1.1 Recommendations for HPRL High Bay Utilization

Planning strategy discussions resulted in the following set of recommendations to define and promote cost and space sharing in the HPRL High Bay:

a. Conduct a detailed study of HPRL collaborative research activities. Develop alternative planning scenarios for relocation of research work to the HPRL High Bay and projected patterns of utilization in years 1-3.

b. Develop environmental and equipment/component requirements for the High Bay space.

c. Create the capability for computer aided planning, design and management by establishing specifications for a Local Area Network (LAN) to integrate the research activities, resources, and personnel involved in High Bay operations.

d. Develop specifications and concept layouts for data retrieval, management and data transfer for High Bay simulation projects.

e. Develop integrated lighting system and control/mixing specifications for the High Bay space. Integrate with the power distribution system of HPRL.

f. Develop a reconfigurable panel system for use in part-task simulation work stations and various full scale mock-ups.

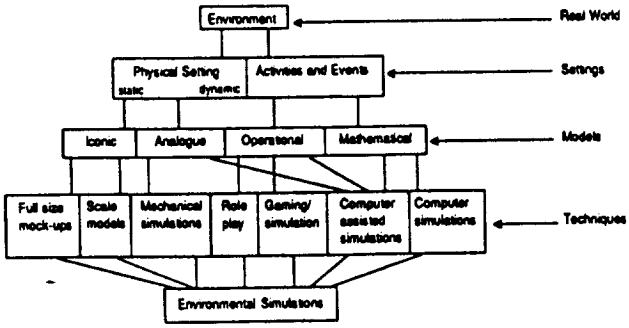
g. Develop procurement specifications for a reconfigurable space frame structure (such as Unistrut®) to provide efficient support of interior environments in the HPRL High Bay.

h. Develop descriptive and qualitative specifications for an Exhibit/Audio Visual Display for visitor orientation and interaction.

i. Carry out a detailed study of potential uses for "generic" research environments, mock-ups and simulators within the High Bay space. **Ref. 1**

1.2 Simulation as Envisioning Tool

To envision the most time/cost effective uses of the HPRL High Bay, various simulation techniques were applied, both realistic and abstract. The most realistic techniques were close in context to the figurative world, while the most abstract utilized computer simulations. By creating a set of physical and operational conditions within a controlled environment, simulation techniques helped to define some basic parameters for the HPRL High Bay performance: who would be involved? what activities would take place? and what conditions or external forces would act upon the proposed outcome–integrated research facility? Through a careful balance of real, virtual, and synthetic elements, simulation provided the optimum milieu for exploring new ideas. **Ref. 2**



Relationship of classification system environment and environment simulations

Note: Analogous to the activities conducted in the HPRL High Bay are the theatrical front/back stage and cinematography sound stage effects. **Ref. 3, 4**

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1. Clipson, C., HPRL Integrated Simulation Project, HPRL, NASA Ames Research Center, APRL, The University of Michigan, January 1988.

2. Clipson, C., Simulating Future Worlds, APRL, Ann Arbor, 1988.

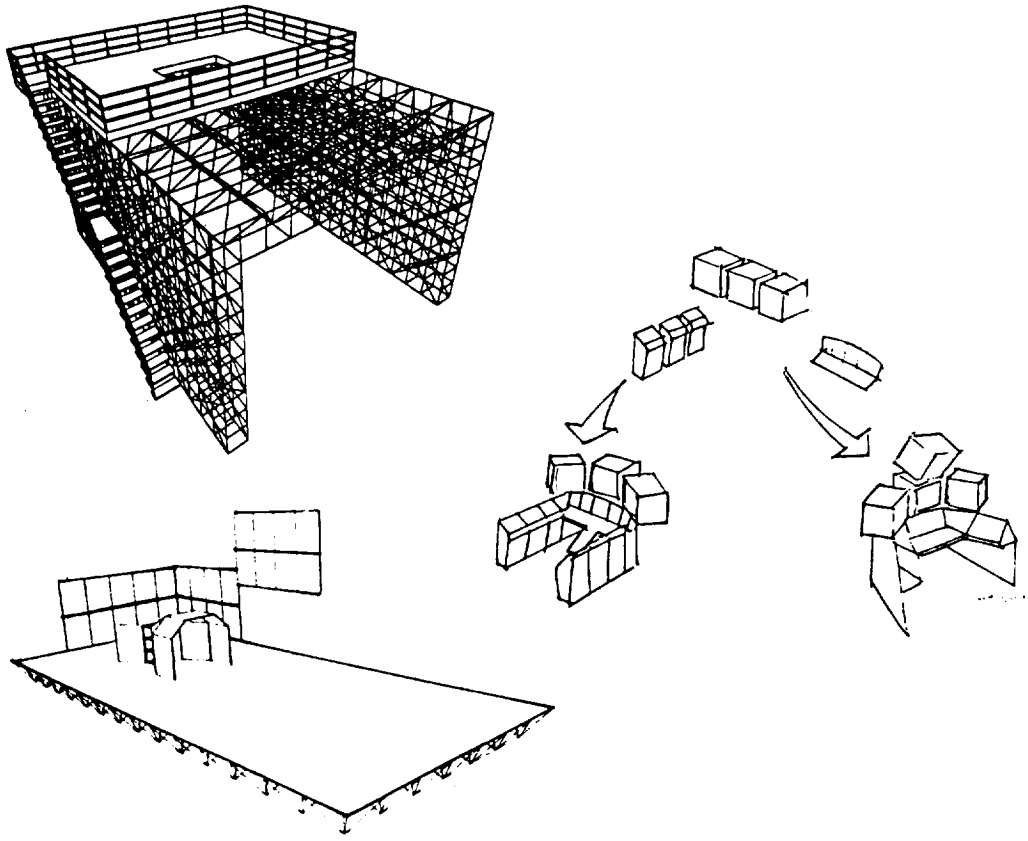
3. Piano, Renzo, Du plateau Beaubourg au Centre Georges Pompidou, Paris, 1987.

4. Finch, Christopher, Special Effects: Creating Movie Magic, Abbeville Press, New York, 1984

1.3 Technology of Reconfigurability

In order to develop more detailed component requirements for the High Bay space, a range of flexible, reconfigurable structures, including generic building concepts and commercially available building/display systems, were studied to be used in building shared experiment testbeds. Demountable space frame structures, dynamic/mobile structures, and flexible pneumatic structures were reviewed.

Ref.
1, 2, 3, 4, 5



1. Clipson, C., HPRL Integrated Simulation Project, HPRL, NASA Ames Research Center, APRL, The University of Michigan, January 1988.
2. Fuller, Buckminster, Inventions, St. Martin's Press, New York, 1981.
3. Space Frame Systems, Unistrut® Corporation, Wayne, Michigan, September 1988.
4. Roland, Conrad, Frei Otto: Tension Structures, Praeger Publishers, New York, 1970.
5. Herzog, Thomas, Pneumatic Structures, Crosby Lockwood Staples, London, 1977.

2.0 Development of 3-D Computer Aided Graphics and Scale Models

2.1 Computer Aided Graphics

Based on these reconfigurable systems studies and the experiment scenarios developed by NASA PI's and their researchers, the APRL research team developed three dimensional computer representations of the HPRL High Bay, testbed mock-ups, and a range of reconfigurable kits of parts Also, the rudimentary inventory/scheduling data base was configured using the main frame systems software. Use of computer graphics and simplified scheduling software enabled a spatial and functional analysis of the HPRL High Bay. These tools also assisted the conceptual design of experimentation testbeds and the control Center, as well as the development of the management system software. **Ref. 1,2**

2.2 Scale Models

Scale models of the High Bay facility and reconfigurable systems were developed. To better illustrate the dynamics of time/space sharing, a video recording was made of the management software model in use, simulating a day in a life of the HPRL High Bay These initial models and computer images, as well as the facility/components specs and guidelines that were developed later, were used as baseline data for a large scale, detailed physical model that illustrates the concept of the reconfigurable testbed facility. This scale model represents three basic facilities: LAB (Laboratory Mockup Environment), HAB (Habitat), and SOS (Space Operations Simulated Environment). The model realistically illustrates the concepts of reconfigurability using miniature replicas of the existing off-the-shelf panel systems, space frame system, and modularized "space rack" elements. Within this model, panels can snap in and out of the wall tracks, solid modules can be replaced by the window panels or "space racks", floor tiles can be removed. **Ref. 1, 2**

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1. Clipson, C., HPRL Integrated Simulation Project, HPRL, NASA Ames Research Center, APRL, The University of Michigan, January 1988.

2. Clipson, C. et al., PHIST Description of Requirements, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1989.

3.0 Pathfinder Human Intelligence Systems Testbed (PHIST)

Once established, the parameters for the HPRL High Bay integrated research environment were established, they were used to detail and document the technical and management requirements for the Ames HPRL High Bay facility, and specifically, the PHIST Control Center (PHISTCON). This entailed the development of core resource requirements and the development of a resource management program and network. **Ref. 1**

3.1 PHIST Control Center Program Plan

To guide the development of these requirements, a Program Plan was created through the joint deliberation of the Ames working group and the APRL/UM team. Four tasks were defined:

- Task 1: Establish PHISTCON requirements
- Task 2: Develop PHIST Core Elements Concepts
- Task 3: Design Computerized Resource Management System
- Task 4: Review Recommendations from Tasks 1-3 **Ref. 1**

3.2 PHIST Control Center Research Operations Process

PHIST Research Operations Process (PROP) defined key research and management activities, roles and responsibilities, as well as identifying the communication networks and resources required to operate PHIST. This operational process was used as the basis for developing a preliminary PHIST management system for use in operating and managing testbeds in the HPRL High Bay facility. **Ref. 2**

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1. Clipson, C. et al., PHISTCON Program Plan, HPRL, NASA Ames Research Center, APRL, The University of Michigan, May 1989.

2. Clipson, C. et al., PROP, PHIST Research Operations Process, HPRL, NASA Ames Research Center, APRL, The University of Michigan, May 1989.

3.3 PHIST Control Center Testbed Specification

This specification established the performance, design, development, and test requirements for the PHIST Control Center (PHISTCON), the prime item core resource of the Pathfinder Human Intelligence Systems Testbed (PHIST). For convenience, this specification was developed using form MIL-STD-490 as a sample format. **Ref. 1**

3.4 PHISTCON Facility Guidelines

Architecture, Engineering, and building contractors selected for the project established Facility Guidelines for the development of PHISTCON to be used by the Ames Operations Group in developing detailed requirements for PHISTCON. **Ref. 2**

3.5 PHIST Description of Requirements

In earlier phases of the project a range of modular, reconfigurable building systems was reviewed for compatibility with HPRL needs. In order to clarify the concept of reconfigurable testbeds, one of these building systems — a steel space frame with a modular panel system and accessories.— was selected for use However, the programmatic guide that was developed for the testbed core resources details the performance requirements for testbed building components regardless of the system finally selected. **Ref. 3**

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1. Clipson, C. et al., PHIST Control Center (PHISTCON) MIL-STD-490 Test Bed Specifications, HPRL, NASA Ames Research Center, APRL, The University of Michigan, June 1989.

2. Clipson, C. et al., PHISTCON Facility Guidelines, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1990.

3. Clipson, C. et al., PHIST Description of Requirements, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1989.

3.6 "Straw Man" Model of the Testbed Concept

In light of NASA Ames directive for an economized "straw man" model of the Testbed Concept, the Addendum to previously generated PHIST Description of Requirements, July 1989 was developed. This alternative concept embodied two models: the BASIC and the COMPREHENSIVE Concept. Both models provide for identical HIST floor structures and an equally foot printed HAB module, but the Comprehensive model has an additional external support structure to permit increased research capabilities. **Ref. 1**

4.0 PHIST Resource Management System Demonstration

The purpose of the demonstration was to help determine the requirements and scope of computer-assisted resource management within PHISTCON, leading to a functional description of a full implementation of such a system.

4.1 PHIST Management System Demonstration Hardware and Software

Recommendations were developed for the hardware and software to be used in the demonstration of a prototype resource management system, featuring high-end and low-end computer systems: high end main frame computers and software and low-end Macintosh software and PCs. Based on these recommendations, the software source code was configured from off-the-shelf Macintosh software. The system is comprised of three elements: a VersaCAD code resource-drafting system, a FoxBASE code resource, and FoxBASE procedures. **Ref. 2.3**

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1. Clipson, C. et al., HIST-Description of Requirements, Addendum, HPRL, NASA Ames Research Center, APRL, The University of Michigan, August 1991.

2. Clipson, C. et al., Software and Hardware Recommendations for Resource Management System Demonstration, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1989.

3. Clipson, C. and Hall, T., PHIST Management System Test and Demonstration Manual-Software Guide, HPRL, NASA Ames Research Center, APRL, The University of Michigan, October 1989.

4.2 PHIST Management System Test and Demonstration Workshop-October/November 1989

The Conceptual Management System Test and Demonstration Workshop utilized a gaming simulation approach based on three roles: Manager, Designer, and Researcher, supported by a Demonstration Coordinator who monitored the operations of a Local Area Network (LAN). The scenarios created for these roles involved the participants in an HPRL research planning exercise in which the participants used the services of the management system to aid them in their tasks.

Three visually separated workstations were installed in the APRL Visualization Laboratory, with one workstation dedicated to each role. Each workstation was equipped with a personal computer and a headset for inter-role communication. Computers were connected to a Local Area Network that provided management tools and shared database access. The computer database was pre-loaded to represent the status of a High Bay testbed on a typical day. A briefing and training manual described the purpose and procedures of the demonstration and the workings of the conceptual management system. All the documents produced during the PHIST Management System Test and Demonstration Workshop, (e.g. memos and experiment requests, print outs of the inventory lists, info requests, print outs of the conceptual testbed designs, and free hand drawings) were collected. These materials formed the basis of an Experiment Implementation Plan. **Ref. 1, 2**

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1. Clipson, C. et al., PHIST Management System Demonstration Assessment, HPRL, NASA Ames Research Center, APRL, The University of Michigan, December 1989.

2. Clipson, C. et al., PHIST Management System Test and Demonstration Experiment Implementation Plan, HPRL, NASA Ames Research Center, APRL, The University of Michigan,October/November 1989.

4.3 PHIST Management System Test and Demonstration Manuals

The manuals prepared for the PHIST Management System Test and Demonstration Workshop included all the information required by those taking part in the Test and Demonstration exercise, including: scenarios for a role playing simulation using a software management system package, a summary of computer aids, and an agenda outlining the issues to be discussed at a Post Test and Demonstration. **Ref. 1**

4.4 PHIST Management System Covisioning Workshop

The PHIST Management System Workshop was conducted at the APRL/UM immediately after the Test and Demonstration of the PHIST Management System. The discussion and evaluation of the PHIST Management System and previously conducted studies resulted in the generation of the set of recommendations for the PHIST Management System. The workshop was recorded by a court recorder. **Ref. 2**

4.5 PHIST Management System Demonstration Assessment

Based on the conclusions and recommendations from the PHIST Management System Covisioning Workshop conducted following the Demonstration, as well as data collected during the Demonstration, the PHIST Management System Demonstration was reviewed by the APRL research team. The review focused on the following: training and demonstration procedures, management system hardware, and management system software. **Ref. 3**

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1. Clipson, C. et al., PHIST Management System Test and Demonstration Manual, Manager, Designer, Researcher, and Demo-Coordinator, HPRL, NASA Ames Research Center, APRL, The University of Michigan, October/November 1989.

2. Clipson, C. et al., PHIST Management System Workshop, HPRL, NASA Ames Research Center, APRL, The University of Michigan, November 1989.

3. Clipson, C. et al., PHIST Management System Demonstration Assessment, HPRL, NASA Ames Research Center, APRL, The University of Michigan, December 1989.

4.6 Presentation of the PHIST Reconfigurable Concepts and PHIST Management System at NASA Ames Research Center, Human Performance Research Laboratory, Moffett Field, California

The developmental phases of the PHIST concept and a PHIST Management System were presented to a large audience of NASA researchers and PIs. The PHIST Management system demonstration was conducted and the reconfigurable concepts were presented with the help of the detailed testbed scale model. **Ref. 1**

5.0 Covisioning Approach

Covisioning stresses a holistic view of an organization's functioning. It emphasizes the value of tapping into the information and innovative ideas available at all levels of the organization, and utilizes a range of collaborative strategies to engage users and researchers in creating a continually innovating organization (e.g. Xerox Park).

5.1 Collaborative Research Environment Facility (CREF)

Establishing the shared environment(s)/resources that lead to information/idea sharing and finally to the development of a shared vision of future projects/concepts is the next step in this collaborative approach. Simulation techniques can be used as an effective tool for covisioning and codesign. **Ref. 2**

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1. Clipson, C. et al., Simulation of NASA Testbed Development and Management, paper for the presentation at NASA Ames Research Center, HPRL, Moffett Field, California,APRL, June 1989.

2. Clipson, C. et al., The Smarter Office, Steelcase Inc., Grand Rapids, Michigan, 1991.

5.2 Human Exploration Demonstration Project (HEDP)

Initially, the Collaborative Research Environment Facility's purpose— to promote research effectiveness and overall productivity —will be implemented through a parallel effort known locally as the Human Exploration Demonstration Project (HEDP). As a collaborative research effort to extend and integrate ongoing work in four divisions of Ames Research Center, HEDP will address the advanced technology requirements necessary to implement an integrated work environment to support a crew in long duration planetary-surface exploration (e.g. Lunar missions, Mars missions, etc.).

Demonstrating the various aspects of human exploration and habitation on extraterrestrial surfaces is a primary objective of HEDP as some of the most intriguing questions concerning human living and working in space address human behavior, endurance and human interaction with technology. The initial scenario for HEDP focuses on a Lunar environment. However, HEDP is considered applicable to a broad spectrum of missions, such as early requirements for robotic systems with control from Earth based workstations or partially automated planetary exploration systems with local control. **Ref. 1**

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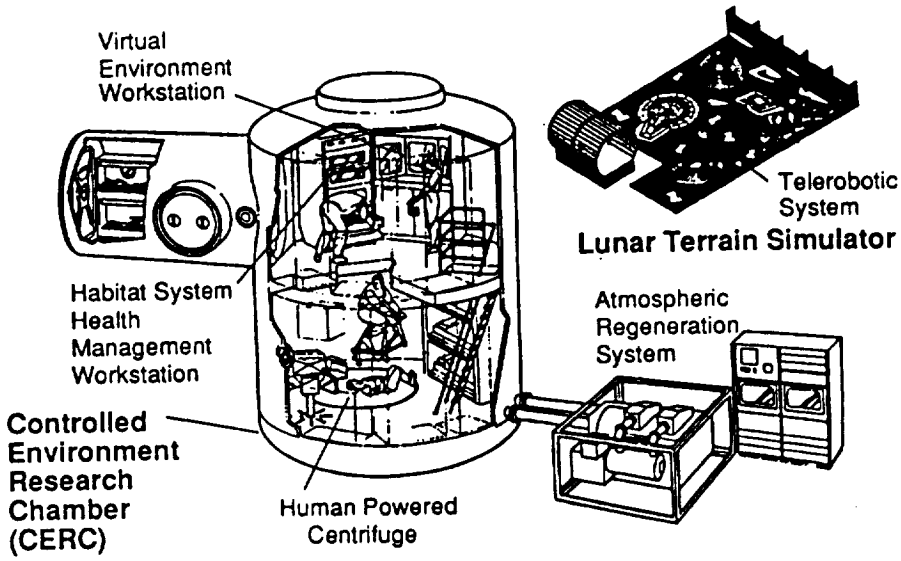
1. Project Plan for Human Exploration Demonstration Project, HPRL, NASA Ames Research Center, February 1992.

Scenarios for the HEDP initial demonstration are already established, and the simulator components are: a full scale simulator of Lunar Habitat (Control Environment Research Chamber in building B-239A), a Lunar terrain surface simulator remotely located in the HPRL High Bay in building 262, and an underlying network connecting the Habitat with the Lunar terrain environment. Artificial intelligence technologies will be employed to maximize autonomy and minimize crew workloads.



Human Exploration Demonstration Project:
"A Day in the Life of a Planetary - Surface Habitat." **Ref. 1**

1. Project Plan for Human Exploration Demonstration Project, HPRL, NASA Ames Research Center, February 1992.

6.0 Conclusions

Collaborative tools and environments aren't just designed to support individuals or group meetings-they're designed to support relationships. Those relationships can be one on one or group interactions, but the key here isn't to optimize the efforts of individuals but to optimize productive relationships between individuals. (and groups)

Collaborative architectures support a process, not an output. One is not building a slaughterhouse where the architectural design directly contributes to a specific outcome. A collaborative environment should be designed to support the various processes of interaction-conversation, sketches, arguments, agreements-and not to predestine or predetermine any specific set of results. The trade-off here is balancing the demand for flexibility and adaptability with the need for some sort of structure that can hold the contexts and contents that these collaborations generate. **Ref. 1**

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1. Schrage, Michael, Shared Minds, The new Technologies of Collaboration, Random House, New York, 1990.

7.0 References

7.1 NASA Documents

1. Clipson, C., HPRL Integrated Simulation Project, HPRL, NASA Ames Research Center, APRL, The University of Michigan, January 1988.

2. Clipson, C. et al., PHIST Description of Requirements, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1989.

3. _____, PHISTCON Program Plan, HPRL, NASA Ames Research Center, APRL, The University of Michigan, May 1989.

4. _____, PROP, PHIST Research Operations Process, HPRL, NASA Ames Research Center, APRL, The University of Michigan, May 1989.

5. _____, PHIST Control Center (PHISTCON) MIL-STD-490 Test Bed Specifications, HPRL, NASA Ames Research Center, APRL, The University of Michigan, June 1989.

6. _____, PHISTCON Facility Guidelines, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1990.

7. _____, PHIST Description of Requirements, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1989.

8. _____, HIST-Description of Requirements, Addendum, HPRL, NASA Ames Research Center, APRL, The University of Michigan, August 1991.

9. _____, Software and Hardware Recommendations for Resource Management System Demonstration, HPRL, NASA Ames Research Center, APRL, The University of Michigan, July 1989.

10. Clipson, C. and Hall, T., PHIST Management System Test and Demonstration Manual-Software Guide, HPRL, NASA Ames Research Center, APRL, The University of Michigan, October 1989.

11. Clipson, C. et al., PHIST Management System Test and Demonstration Manual, Manager, Designer, Researcher, and Demo-Coordinator, HPRL, NASA Ames Research Center, APRL, The University of Michigan, October/November 1989.

12. _____, PHIST Management System Test and Demonstration Experiment Implementation Plan, HPRL, NASA Ames Research Center, APRL, The University of Michigan,October/November 1989.

13. Clipson, C. et al., PHIST Management System Demonstration Assessment, HPRL, NASA Ames Research Center, APRL, The University of Michigan, December 1989.

14. _____, PHIST Management System Workshop, HPRL, NASA Ames Research Center, APRL, The University of Michigan, November 1989.

15. _____, Simulation of NASA Testbed Development and Management, paper for the presentation at NASA Ames Research Center, HPRL, Moffett Field, California,APRL, June 1989.

16. Project Plan for Human Exploration Demonstration Project, HPRL, NASA Ames Research Center, February 1992.

7.2 Other References

1. Clipson, C., Simulating Future Worlds, APRL, Ann Arbor, 1988.

2. Clipson, C. et al, The Smarter Office, Steelcase Inc., Grand Rapids, Michigan, 1991.

3. Finch, Christopher, Special Effects: Creating Movie Magic, Abbeville Press, New York, 1984.

4. Fuller, Buckminster, Inventions, St. Martin's Press, New York, 1981.

5. Herzog, Thomas, Pneumatic Structures, Crosby Lockwood Staples, London, 1977.

6. Piano, Renzo, Du plateau Beaubourg au Centre Georges Pompidou, Paris, 1987.

7. Roland, Conrad, Frei Otto: Tension Structures, Praeger Publishers, New York, 1970.

8. Schrage, Michael, Shared Minds, The new Technologies of Collaboration, Random House, New York, 1990.

9. Space Frame Systems," Brochure, Unistrut® Corporation, Wayne, Michigan, September 1988.